NASA/TM—2000–209891, Vol. 53

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NASA/TM—2000–209891, Vol. 53

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Jaime Nickeson, Editors

Volume 53

BOREAS RSS-7 Landsat TM LAI Images of the SSA and NSA

Jing Chen and Josef Cihlar
Canada Centre for Remote Sensing, Ottawa, Ontario, Canada

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

August 2000

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BOREAS RSS-7 Landsat TM LAI Images of the SSA and NSA

Jing M. Chen, Josef Cihlar

Summary

The BOREAS RSS-7 team used Landsat TM images processed at CCRS to produce images of LAI for the BOREAS study areas. Two images acquired on 06-Jun and 09-Aug-1991 were used for the SSA, and one image acquired on 09-Jun-1994 was used for the NSA. The LAI images are based on ground measurements and Landsat TM RSR images. The data are stored in binary image-format files.

Note that some of the data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See Section 8.2 for details.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-07 Landsat TM LAI Images of the SSA and NSA

1.2 Data Set Introduction

These Leaf Area Index (LAI) images were generated in response to the need within the BOReal Ecosystem-Atmosphere Study (BOREAS) modeling community for adequate spatial and temporal coverage of estimated vegetation indices across the BOREAS region.

1.3 Objective/Purpose

The objective of this study was to provide spatially referenced LAI maps for landscape and regional ecosystem analysis and modeling in the Southern Study Area (SSA) and Northern Study Area (NSA) of the BOREAS.

1.4 Summary of Parameters

LAI images

1.5 Discussion

This data set was prepared as a part of continuous investigation by the Remote Sensing Science (RSS)-07 team. LAI maps were calculated using Landsat Thematic Mapper (TM) images acquired on 06-Jun-1991 (SSA), 09-Aug-1991 (SSA), and 09-Jun-1994 (NSA). These LAI maps are produced with atmospherically corrected Landsat TM band 3, 4, and 5 data and field measurements of LAI. The link between the image and field measurements is based on the correlation between the Reduced Simple Ratio (RSR) and the field LAI values. RSR is the simple ratio (SR), near-infrared (NIR) reflectance/red reflectance, reduced by a factor based on the mid-infrared (MIR) reflectance (TM band 5), i.e.

RSR = SR(1-(MIR-MIRmin)/(MIRmax-MIRmin))

where MIRmin and MIRmax are the minimum and maximum MIR reflectance in the image, determined from the histogram of each image. They are 0.05 and 0.22 for the 06-Jun and 09-Aug images, and 0.06 and 0.24 for the 09-Jun image. Generally the correlation takes the following form:

LAI = intercept + Slope * RSR

In this LAI calculation, the following parameters were used for both the SSA and the NSA: intercept = 1.75, slope = 0.46. Unlike our previous techniques (i.e., regional LAI maps from the Advanced Very High Resolution Radiometer (AVHRR), no land cover information was used in the LAI calculation. This may reduce the error propagation caused by misclassification or grouping of spectral data and provides more details of spatial variation of LAI because of the sensitivity of the MIR band to vegetation cover. The disadvantage of not using the land cover map is that in areas of low canopy density, the unknown background reflectance can affect the determination of LAI; however, this bias is very small. For a small number of pixels, the calculated LAI is unreasonably high, and therefore an upper limit of an LAI of 6 is imposed. The advantages of using RSR are discussed by Brown et al. (1999).

The theories of field LAI measurements are documented in the BOREAS RSS-07 LAI, Gap Fraction, and FPAR Data document. The LAI data sets have been geometrically rectified. The LAI maps were produced with encoded LAI range values. Image processing and penetration of LAI maps were conducted at the Canada Centre for Remote Sensing (CCRS).

1.6 Related Data Sets

BOREAS Level-3b Landsat TM Imagery: At-sensor Radiance in BSQ Format
BOREAS RSS-07 Regional LAI and FPAR Images From Ten-Day AVHRR-LAC Compsites

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Jing M. Chen
Mr. Xiaoyuan Geng (Ph.D. Candidate)

2.2 Title of Investigation

Retrieval of Boreal Forest Leaf Area Index From Multiple Scale Remotely Sensed Vegetation Indices

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3. Theory of Measurements

The theory of Landsat TM has been discussed in the BOREAS documentation for the Landsat Level-3b data. Relevant portions have been repeated throughout.

The Landsat TM sensor collects imagery of Earth in seven spectral bands ranging from the blue to the thermal IR portion of the electromagnetic spectrum. Multispectral classification of this imagery can be performed by identifying areas that are representative of land cover types to be classified. Statistics can be computed in these spectral bands for each feature type. A maximum likelihood classifier can then be applied by identifying the most likely land cover type for each pixel in the image based on the statistics of the training fields.

The following spectral bands are collected by the TM sensor:

Channel	Wavelength (μ)	Primary Use
1	0.45 - 0.52	Coastal water mapping, soil vegetation differentiation, deciduous/coniferous differentiation.
2	0.52 - 0.60	Green reflectance by healthy vegetation.
3	0.63 - 0.69	Chlorophyll absorption for plant species differentiation.
4	0.76 - 0.90	Biomass surveys, water body delineation.

5	1.55 - 1.72	Vegetation moisture measurement, snow cloud differentiation.
6	10.4 - 12.5	Plant heat stress measurement, other thermal mapping.
7	2.08 - 2.35	Hydrothermal mapping.

4. Equipment

4.1 Sensor/Instrument Description

The TM sensor system records radiation from the seven bands in the electromagnetic spectrum described in Section 3. It has a telescope that directs the incoming radiant flux obtained along a scan line through a scan line collector to the visible and NIR focal plane, or to the MIR and thermal-IR cooled focal plane. The detectors for the visible and NIR bands (1 to 4) are four staggered linear arrays, each containing 16 silicon detectors. The two MIR detectors are 16 indium-antimonide cells in a staggered linear array, and the thermal-IR detector is a four-element array of mercury-cadmium-telluride cells.

4.1.1 Collection Environment

The Landsat satellite orbits Earth at an altitude of 705 km.

4.1.2 Source/Platform

Landsat TM satellite.

4.1.3 Source/Platform Mission Objectives

The Landsat TM is designed to respond to and measure both reflected and emitted Earth surface radiation to enable the investigation, survey, inventory, and mapping of Earth's natural resources.

4.1.4 Key Variables

Reflected radiation, emitted radiation, and temperature.

4.1.5 Principles of Operation

The TM is a scanning optical sensor operating in the visible and IR wavelengths. It contains a scan mirror assembly that directly projects the reflected Earth radiation onto detectors arrayed in two focal planes. The TM achieves better imagery resolution, sharper color separation, and greater in-flight geometric and radiometric accuracy for seven spectral bands simultaneously than the previous generation sensor, the Multispectral Scanner (MSS). Data collected by the TM sensor are transmitted back to Earth receiving stations for processing.

4.1.6 Sensor/Instrument Measurement Geometry

The TM sensor depends on the forward motion of the spacecraft for the along-track scan and uses a moving mirror assembly to scan in the cross-track direction (perpendicular to the spacecraft). The instantaneous field of view (IFOV) for each detector from bands 1 through 5 and band 7 is equivalent to a 30-m square when projected to the ground; band 6 (the thermal-IR band) has an IFOV equivalent to a 120-m square.

4.1.7 Manufacturer of Sensor/Instrument

NASA GSFC
Greenbelt, MD 20771

Hughes Aircraft Corporation
Santa Barbara, CA

4.2 Calibration

The internal calibrator, a flex-pivot-mounted shutter assembly, is synchronized with the scan mirror, oscillating at the same 7-Hz frequency. During the turn-around period of the scan mirror, the shutter introduces the calibration source energy and a black direct-current restoration surface into the 100-detector field of view.

The calibration signals for bands 1 through 5 and band 7 are derived from three regulated tungsten-filament lamps. The calibration source for band 6 is a blackbody with three temperature selections, commanded from the ground. The method for transmitting radiation to the moving calibration shutter allows the tungsten lamps to provide radiation independently and to contribute proportionately to the illumination of all detectors.

4.2.1 Specifications

Band	Radiometric Sensitivity [NE(dP)]*
1	0.8%
2	0.5%
3	0.5%
4	0.5%
5	1.0%
6	0.5 K [NE(dT)]
7	2.4%

Ground IFOV	30 m (Bands 1-5, 7)
	120 m (Band 6)
Avg. altitude	699.6 km
Data rate	85 Mbps
Quantization levels	256
Orbit angle	8.15 degrees
Orbital nodal	
Period	98.88 minutes
Scan width	185 km
Scan angle	14.9 degrees
Image overlap	7.6 %

* N.B. The radiometric sensitivities are the noise-equivalent reflectance differences for the reflective channels expressed as percentages [NE(dP)] and temperature differences for the thermal-IR bands [NE(dT)].

4.2.1.1 Tolerance

The TM channels were designed for a noise-equivalent differential represented by the radiometric sensitivity shown in Section 4.2.1.

4.2.2 Frequency of Calibration

The absolute radiometric calibration between bands is maintained by using internal calibrators that are located between the telescope and the detectors and are sampled at the end of a scan.

4.2.3 Other Calibration Information

Relative within-band radiometric calibration, to reduce "striping," is provided by a scene-based procedure called histogram equalization. The absolute accuracy and relative precision of this calibration scheme assumes that any changes in the in the optics of the primary telescope or the "effective radiance" from the internal calibrator lamps are insignificant in comparison to the changes in detector sensitivity and electronic gain and bias with time and that the scene-dependent sampling is sufficiently precise for the required within-scan destriping from histogram equalization.

Each TM reflective band and the internal calibrator lamps were calibrated prior to launch using lamps in integrating spheres that were in turn calibrated against lamps traceable to calibrated National Bureau of Standards lamps. Sometimes the absolute radiometric calibration constants in the "short-term" and "long-term parameters" files used for ground processing have been modified after launch because of inconsistency within or between bands, changes in the inherent dynamic range of the sensors, or a desire to make quantized and calibrated values from one sensor match those from another.

5. Data Acquisition Methods

These data were acquired from the Landsat 5 TM sensor and received from CCRS who purchased it from the Earth Observation Satellite Corporation (EOSAT). As received from CCRS, the image had been processed from raw telemetry to a systematically corrected product within the CCRS MOSAICS system. Atmospheric correction was applied to the systematically corrected data. Surface reflectance was calculated using the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) (Vermote et al., 1997) model, using inputs of a continental airmass, midlatitude summer, a uniform target, and 30 km atmospheric visibility. Modified SR was calculated using maximum IR reflectance of 22% and 24%, and minimum IR reflectance of 5% and 6% for the SSA and NSA, respectively (Brown et al., 1999). Field LAI data were taken from the published data of Chen (1996) and Brown et al. (1999). Detailed procedures are documented in Chen et al. (1997).

6. Observations

6.1 Data Notes

The radiometric quality of the imagery is acceptable.

6.2 Field Notes

None given.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The calculated LAI images cover portions of a full Landsat TM scene. The data set boundaries have well-defined coordinates.

The North American Datum of 1927 (NAD27) Universal Transverse Mercator (UTM) coordinates of the TM image of NSA acquired on 09-Jun-1994 are:

```
                     UTM         UTM
                    Easting     Northing
Northwest           501220.5    6239553.0
Southeast           562660.5    6178113.5
```

The NAD27 UTM coordinates of the TM image of SSA acquired on 09-Aug-1991:

```
                     UTM         UTM
                    Easting     Northing
Northwest            451000     6042000
Southeast            556000     5937000
```

The NAD27 UTM coordinates of the TM image of SSA acquired on 06-Jun-1991:

	UTM Easting	UTM Northing
Northwest	471200	6016960
Southeast	532640	5955520

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

These data were gridded to a cell size of 30 meters from the original nominal resolution of 28.5 meters by the MOSAICS system.

7.1.4 Projection

Universal Transverse Mercator (UTM).

7.1.5 Grid Description

SSA: UTM Zone 13, NAD27
NSA: UTM Zone 14, NAD27

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The images used were acquired in 1991 for the SSA, and in 1994 for the NSA.

7.2.2 Temporal Coverage Map

Image Date	WRS* (Path/Row)	Solar Elevation (degrees)	Solar Azimuth (degrees)	Radiometric Quality
06-Jun-1991	37/22-23	47.41	139.83	Good
09-Aug-1991	37/22	43.25	141.88	Good
09-Jun-1994	33/21	37.65	140.81	Good

* WRS -- World Reference System

7.2.3 Temporal Resolution

The Landsat TM satellite revisit frequency is 16 days for each path/row; however, in the BOREAS region, the overlap between adjacent scene paths is about 50%. Thus, the frequency for some areas can be 8 days.

7.3 Data Characteristics

7.3.1 Parameter/Variable

Leaf Area Index (LAI)

7.3.2 Variable Description/Definition

The definition of LAI is one half the total leaf area per unit ground surface area. The reduced simple ratio is:

RSR = SR * (1-(MIR-MIRmin)/(MIRmax-MIRmin))

where MIRmin and MIRmax are the minimum and maximum MIR reflectance in an image.

7.3.3 Unit of Measurement
LAI - square meters of leaf area / square meter of ground surface

7.3.4 Data Source
Landsat TM 5 sensor.

7.3.5 Data Range
LAI : 1 - 55 (0 for water) for LAI 0 - 5.4

7.4 Sample Data Record
Not applicable for image data.

8. Data Organization

8.1 Data Granularity
The smallest unit of data tracked by the BOREAS Information System (BORIS) is a binary and TIFF image pair acquired on a single day.

8.2 Data Format(s)

8.2.1 Uncompressed Files
This data set contains the following six files:

File Description/Name	Format	Npix	Nlines	File Size
NSA_LAI_94JUNE.IMG	Raw Binary	2048	2048	4Mb
NSA_LAI_94JUNE.TIFF	TIFF			2Mb
SSA_LAI_91JUNE.IMG	Raw Binary	2048	2048	4Mb
SSA_LAI_91JUNE.TIFF	TIFF			2Mb
SSA_LAI_91AUG.IMG	Raw Binary	3500	3500	12Mb
SSA_LAI_91AUG.TIFF	TIFF			6Mb

The *.IMG files are all 8-bit binary images. The file architecture is the same as that of any common image file: the first byte is the first pixel of the first line, the second byte is the second pixel of the first line,.(the first pixel in the second line of image 1 is the 2049th byte). The *.TIFF files are TIFF versions of the *.IMG files and are for display purposes only.

8.2.2 Compressed CD-ROM Files
On the BOREAS CD-ROMs, the image files been compressed with the Gzip (GNU zip) compression program (file_name.gz). These data have been compressed using gzip version 1.2.4 and the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip uses the Lempel-Ziv algorithm (Welch, 1994) also used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (with the -d option) or gunzip. Gzip is available from many Web sites (for example, the ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

LAI maps were calculated using Landsat TM images acquired on 06-Jun-1991 (SSA), 09-Aug-1991 (SSA), and 09-Jun-1994 (NSA). These LAI maps are produced with atmospherically corrected Landsat TM band 3, 4, and 5 data and field measurements of LAI. The link between the image and field measurements is based on the correlation between the RSR and the field LAI values. RSR is the SR, NIR reflectance/red reflectance, reduced by a factor based on the MIR reflectance (TM band 5), i.e.

$$RSR = SR(1-(MIR-MIR_{min})/(MIR_{max}-MIR_{min}))$$

where MIR_{min} and MIR_{max} are the minimum and maximum MIR reflectance in the image determined from the histogram of each image. They are 0.05 and 0.22 for the 06-Jun and 09-Aug images, and 0.06 and 0.24 for the 09-Jun image. Generally, the correlation takes the following form:

$$LAI = intercept + Slope * RSR$$

In this LAI calculation, the following parameters were used for both the SSA and the NSA: intercept = 1.75, slope = 0.46.

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff copied the American Standard Code for Information Interchange (ASCII) and compressed the binary files for release on Compact Disk - Read-Only Memory (CD-ROM).

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

$$RSR = SR(1-(MIR-MIR_{min})/(MIR_{max}-MIR_{min}))$$
$$LAI = intercept + Slope * RSR$$

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

The sources of error in the LAI maps could result from a number of factors. The correlation between LAI and modified SR is empirical. Also, the use of MIR channel in the empirical relationship may be influenced by the surface water conditions. Other potential sources of error, such as those caused by image correction and projection, are minor in comparison.

10.2 Quality Assessment by Source

10.2.1 Data Validation by Source

Even though we have inspected the final LAI values for about 10 known sites on each image, no extensive validation has been done. Since our source of RSR data came from the scenes 06-Jun-1991 (SSA) and 09-Jun-1994 (NSA), we believe LAI images of these two dates are most useful.

10.2.2 Confidence Level/Accuracy Judgment

None given.

10.2.3 Measurement Error for Parameters

Ground LAI measurement errors are about 25% (Chen et al., 1997). The RSR may be sensitive to rainfall events. In particular, the 09-Aug-1991 scene was not used in the RSR-LAI algorithm development, so it is less reliable.

10.2.4 Additional Quality Assessment

Not applicable.

10.2.5 Data Verification by Data Center

Data were examined for general consistency and clarity.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

Clouds in the 06-Jun-1991 scene of the SSA show up in a diagonal strip across the image. The areas under the clouds have LAI in the range of 2.5-3.0. The 09-Aug-1991 scene, which covers the same area, is clear and is therefore provided here as a remedy for the cloud effect. It is known, however, that summer scenes are less reliable for LAI retrieval because of the increased background effect, which overestimates LAI by about 15-25%, and reduces the spatial variation of LAI.

For jack pine stands, the LAI in the 09-Aug-1991 scene of the SSA seems to be about 20% high because of understory development, while this background effect in other stand types is more suppressed by the use of the MIR (TM band 5) data.

11.3 Usage Guidance

Spring scenes (06-Jun-1991 and 09-Jun-1991) are the most suitable for LAI mapping in the SSA and NSA (Chen and Cihlar, 1996). However, in the SSA, the 06-Jun-1991 scene is affected by clouds. The 09-Aug-1991 scene is therefore provided as a reference to remove the cloud effects. The LAI change is small for conifer stands and higher for deciduous and grassland.

Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

11.4 Other Relevant Information

None.

12. Application of the Data Set

These images can be used to investigate the spatial distribution of LAI over the mapped areas.

13. Future Modifications and Plans

None given.

14. Software

14.1 Software Description

Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

Gzip is available from many Web sites across the Internet (for example, ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

15. Data Access

The Landsat TM LAI images of the SSA and NSA are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

The data can be made available on 8-mm or Digital Archive Tape (DAT) media.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None given.

19. List of Acronyms

```
6S      - Second Simulation of the Satellite Signal in the Solar Spectrum
ASCII   - American Standard Code for Information Interchange
AVHRR   - Advanced Very High Resolution Radiometer
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
BSQ     - Band Sequential
CCRS    - Canada Centre for Remote Sensing
CD-ROM  - Compact Disk-Read-Only Memory
DAAC    - Distributed Active Archive Center
DAT     - Digital Archive Tape
DN      - Digital Number
EOS     - Earth Observing System
EOSAT   - Earth Observation Satellite Corporation
EOSDIS  - EOS Data and Information System
EROS    - Earth Resources Observation System
FPAR    - Fraction of PAR absorbed by plant canopies
GIS     - Geographic Information System
GSFC    - Goddard Space Flight Center
IFC     - Intensive Field Campaign
IFOV    - Instantaneous Field-of-View
IR      - Infrared
ISLSCP  - International Satellite Land Surface Climatology Project
LAI     - Leaf Area Index
LCC     - Lambert Conformal Conic
Mbps    - Megabytes per second
MIR     - Mid-Infrared
MRSC    - Manitoba Remote Sensing Centre
MSS     - Multispectral Scanner
NAD27   - North American Datum of 1927
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NAD83    - North American Datum of 1983
NASA     - National Aeronautics and Space Administration
NDVI     - Normalized Difference Vegetation Index
NEdT     - Noise Equivalent Differential Temperature
NIR      - Near-Infrared
NOAA     - National Oceanic and Atmospheric Administration
NSA      - Northern Study Area
ORNL     - Oak Ridge National Laboratory
PANP     - Prince Albert National Park
PAR      - Photosynthetically Active Radiation
PASS     - Prince Albert Satellite Station
RSR      - Reduced Simple Ratio
RSS      - Remote Sensing Science
SR       - Simple Ratio
SSA      - Southern Study Area
TM       - Thematic Mapper
URL      - Uniform Resource Locator
UTM      - Universal Transverse Mercator
WRS      - World Reference System
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The BOREAS RSS-7 team used Landsat TM images processed at CCRS to produce images of LAI for the BOREAS study areas. Two images acquired on 06-Jun and 09-Aug-1991 were used for the SSA, and one image acquired on 09-Jun-1994 was used for the NSA. The LAI images are based on ground measurements and Landsat TM RSR images. The data are stored in binary image-format files.

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